NASA Innovative Advanced Concepts

Triton Hopper: Exploring Neptune's Captured Kuiper Belt Object

Completed Technology Project (2015 - 2016)

Project Introduction

Phase II for the Triton Hopper will focus on retiring the risks identified in Phase I and providing better detail and alternate conceptual options. The three main risks to be addressed include Triton hopper mission, propellant collection, and propulsion performance. For the Triton mission both delivery to Triton in a timely manner ~ 15 yrs and safe takeoff and landing of the hopper on the Triton terrain will be explored. For propellant collection a bevameter experiment will be performed on a small sample of frozen nitrogen to assess ways to best gather the frozen nitrogen propellant. For the propulsion performance ways will be explored to heat the propellant to higher temperatures and or to reduce dry mass to enable further hops. Using these three products two Compass concurrent engineering runs will be performed; the first of which focusses on integrating the findings of mission/propellant collection and the second on integrating the findings which increase hop distance. Phase II will end with roadmapping technology development solutions as well as using such techniques for other icy worlds to gather propellants for hopping.

Anticipated Benefits

The Triton Hopper addresses NASA's strategic goals 2, 3, and 6 by exploring the Triton environment, the first exploration of a KBO which could hold clues to how the solar system formed. It will create new technologies in the form of a semi-autonomous planetary hopping vehicles which use frozen gases for propellants and would capture the imaginations of educators and students by sharing with them exploration of a completely new envi- ronment on a foreign world. Triton Hopper will also address the NASA technology areas of Space Power and Energy Storage, Robotics and Autonomous Systems, Communications and Navigation Systems, Science Instru- ments and Sensors, Nanotechnology, Materials, and Thermal Management Systems. The Triton Hopper study will be the first real definition of a \xd4frozen gas rock' powered hopper, since prior ISRU fuel concepts were fed with atmospheric gas. The Triton Hopper would be a pathfinder in combining ISRU acqui- sition and science, since the sampling system doubles as the propellant production system. Addressing the challenge of autonomous hopper exploration in an extremely cold outer solar system environment, Triton Hopper serves as a pathfinder for other exploration of the frozen surfaces of icy moons such as Enceladus and Europa, as well as more distant objects such as Sedna, Charon, Centaurs, and Trans-Neptunian and Kuiper-belt objects.

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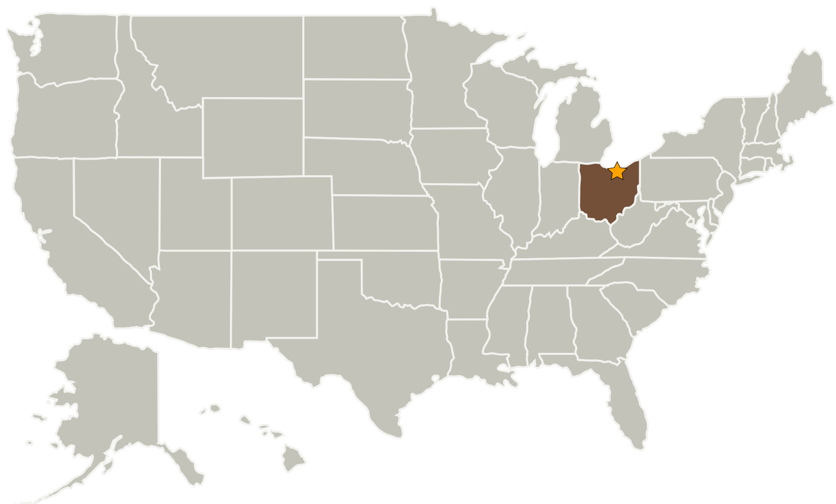
Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Glenn Research Center(GRC)	Lead Organization	NASA Center	Cleveland, Ohio
Johns Hopkins University Applied Physics Laboratory(JHU/APL)	Supporting Organization	R&D Center	Laurel, Maryland
Vantage Partners, LLC	Supporting Organization	Industry Small Disadvantaged Business (SDB)	

Primary U.S. Work Locations
Ohio

Project Transitions

July 2015: Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Glenn Research Center (GRC)

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

Eric A Eberly

Principal Investigator:

Steven R Oleson

Co-Investigator:

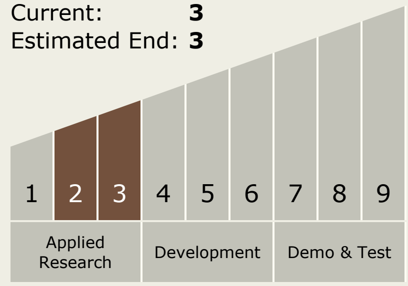
Geoffrey A Landis

June 2016: Closed out

Closeout Summary: The Triton Hopper is a mission concept study funded as a phase 1 effort by the NASA NIAC program. This work serves as the final report for this effort. Neptune's moon Triton is a fascinating object, a dynamic moon with an atmosphere, and geysers.1 Triton is unique in the outer solar system in that it is most likely a captured Kuiper belt object (KBO) - a leftover building block of the solar system.2 When Voyager flew by, it was the coldest body yet found in our solar system (33 K), yet had volcanic activity, geysers, and a thin atmosphere (see figures Figure 1-1 and Figure 1-2.) It is covered in ices made from nitrogen, water, and carbon dioxide, and shows surface deposits of tholins, organic compounds that may be precursor chemicals to the origin of life. At a distance of over 30 astronomical units, it would be by far the most distant object ever landed on by a spacecraft. The Triton Hopper effort set out to design a mission to not merely land, but repeatedly fly across the surface of Triton, utilizing the volatile surface ices (primarily nitrogen) as propellant to launch across the surface and explore all the moon's varied terrain. We have determined that such a hopper can be developed using simple methods of collection and propulsion. Gathering 100 kilograms of surface nitrogen ice with either a robotic scoop, or atmospheric gas using a cryopump provides sufficient propellant to allow this ~300 kg, highly instrumented lander to hop 5 km across the surface once a month, using a low-temperature radioisotope-thermal engine. More sophisticated propulsion could increase the flight range. Two years of hopping would allow this lander to hop 150 km and visit 30 sites! The final hopper design is shown in Figure 1-3. The concept of operations for the hopper is shown in Figure 1-4. While the phase I effort focused primarily on design of the hopper vehicle, not the delivery to Triton, a top-level analysis was performed to show that it is possible to deliver the vehicle from Earth to Triton and land it on the surface. Figure 1-5 summarizes the delivery trades. While use of nuclear electric propulsion would allow getting into low Triton orbit (and thereby minimizing the Triton descent propulsion system size), the baseline design choice was use of a solar electric propulsion (SEP) stage and aerocapture system, leveraging the investment in SEP by other NASA technology efforts, including the piloted Mars mission's use of SEP and aerocapture. Using the SEP and aerocapture system produced a launch and delivery concept similar to that explored in Mission Trades for Aerocapture at Neptune (R. Bailey, M. Noca, Mission Trades for Aerocapture at Neptune, AIAA-2004-3843, 40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Fort Lauderdale, FL, July 2004). As such, the concept developed in the reference was assumed to be the delivery concept to Neptune. New trajectories to Neptune using SEP and aerocapture for a 2029 launch date were developed as was a notional mission and combined solid/biprop landing stage to get the hopper nearly to the surface. The baseline conops for the delivery to Triton is shown in Figure 1-6. The main focus of this NIAC effort was to determine feasible methods of gathering, processing and using in-situ propellant. According to Voyager the surface is predominantly nitrogen, in the form of both ice and snow form on the surface (Figure 1-7). Triton has a very thin atmosphere (~1 Pa), again mostly of nitrogen. Both surface and atmosphere sources were analyzed for propellant collection. Since nitrogen was accessible both frozen on the surface and in the atmosphere, it was selected as the easiest propellant to utilize and process. Four main approaches to gathering propellant were considered, each having various options (e.g., shovels or drills or scrapers). These methods are shown in Figure 1-8. The obvious choice is to gather the propellant in its frozen form on the surface. Since the science system requires a robotic arm with a scoop to gather samples for analyzing, a simple approach is to reuse this scoop to gather frozen nitrogen. Even at low temperatures, nitrogen ice is n

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**



Technology Areas

Primary:

- TX01 Propulsion Systems
  └ TX01.2 Electric Space Propulsion
    └ TX01.2.4 Electrothermal

Target Destination

Outside the Solar System

Project Website:

https://www.nasa.gov/directorates/spacetech/niac/index.html#.VQb6I0jJzyE